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Persistence and Carryover Effect of Imazapic and Imazapyr in Brazilian Cropping Systems[1]

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Abstract: Field studies were conducted in 1999 to 2000 on a clay soil and a sandy-loam soil in Londrina and Palmeira, PR, Brazil, respectively, to determine the persistence and carryover effect of a mixture of imazapic and imazapyr, applied to imidazolinone-tolerant corn, on rotational crops of soybean, edible bean, wheat, and corn in two different planting systems (no till and tillage). Main plots were herbicide treatments (0, 52.5 + 17.5, and 105 + 35 g ai/ha for imazapic and imazapyr, respectively) and subplots were five intervals (0, 30, 60, 90, and 120 d) between the herbicide application and rotational crop planting. Soil samples were collected for a cucumber bioassay and chemical residues analysis at each time interval. The dissipation time (DT_{50}) of the herbicides in the soil was greater in Londrina than Palmeira, for both imazapic (54 d vs. 27 d, respectively) and imazapyr (40 d vs. 33 d, respectively), probably due to the lower pH and greater clay content of the soil in Londrina compared with Palmeira. The DT_{50} for both herbicides tended to increase slightly in no-till compared with conventional tillage but the differences were not great. Soybean was the least sensitive rotational crop, with a period for no yield drag (PINYD) of 87 d in Londrina and 88 d in Palmeira. Wheat and edible bean showed intermediate sensitivity. The PINYD for wheat and edible bean was 99 and 98 d for Londrina and 91 and 97 d for Palmeira, respectively. Corn was the most sensitive, with a PINYD of 117 d in Londrina and 97 d in Palmeira. Cucumber was more sensitive to imazapic and imazapyr residues than the rotational crops and should be an effective bioassay to indicate when rotational crops can be safely planted.

Nomenclature: Corn, *Zea mays* L.; cucumber, *Cucumis sativus* L.; edible bean, *Phaseolus vulgaris* L., soybean, *Glycine max* (L.) Merr.; wheat, *Triticum aestivum* L.

Additional index words: Crop tolerance, imidazolinone, herbicide carryover, dissipation time, planting interval, soil bioassay.

Abbreviations: ALS, acetolactate synthase; CPINI, cucumber planting interval with no injury; DAP, days after planting; DAT, days after treatment; DT_{50}, interval (in days) to degrade 50% of the herbicide rate applied in the soil; LCHS, lowest concentration of the herbicide in the soil which causes crop injury; PINYD, the period between herbicide application and rotational crop planting with no yield drag.

INTRODUCTION

Imazapyr and imazapic are broad-spectrum, imidazolinone herbicides that control many grasses and broadleaf weeds, as well as woody plants. Imazapyr has been used to control weeds in conifers (*Pinus* spp.), rubber tree [*Hevea brasiliensis* (Willd.) Muell.-Arg.], sugar cane (*Saccharum officinarum* L.) and noncrop areas (Beardmore et al. 1991; Leite et al. 1998) and imazapic is used in sugar cane and peanut (*Arachis hypogaea* L.) (Richburg et al. 1996; Wilcut et al. 1994). Both compounds are applied POST when weeds are actively growing, but they also have soil residual activity.

Organic matter and pH significantly affect the behavior of the imidazolinones in soil (Stougaard et al. 1990). Adsorption increases as pH decreases and is the greatest in soils with high organic matter or clay content at low pH (Loux et al. 1989). The water solubility (25 C, pH 7) of imazapyr and imazapic is relatively high at 11,272 and 2,150 ppm, respectively (Rodrigues and Almeida 1998). However, these herbicides do not readily leach under field conditions despite high water solubility and low soil adsorption (Mangels 1991). This may be due to soil surfaces becoming more acidic as moisture levels decrease (Mangels 1991). Mobility is also influenced under most field conditions by movement of these herbi-

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Table 1. Precipitation and average temperature during the crop season in Londrina and Palmeira, PR, Brazil.

Time	Precipitation		Air temperature (average)	
	Londrina	Palmeira	Londrina	Palmeira
DAA[a]	mm		C	
0–30	182.9	245.6	21.4	17.2
31–60	129.6	127.1	23.2	19.2
61–90	224.1	134.8	23.9	20.6
91–120	263.0	157.2	23.7	21.1
121–150	212.2	223.9	24.3	21.5
151–180	92.6	103.1	24.2	20.9
181–210	94.9	83.7	20.8	17.3
211–240	102.8	84.2	17.3	13.7
241–270	135.7	225.1	15.9	12.4
271–300	86.3	115.2	17.7	13.2

[a] Abbreviation: DAA, days after herbicide application.

cides to the soil surface through capillary action and evaporation (Mangels 1991).

The primary dissipation mechanism for imidazolinones under aerobic conditions is by microbial degradation with a small contribution from photolysis (Loux and Reese 1993). Conditions that tend to favor microbial activity, such as warm, moist soils are the conditions under which the imidazolinones are most rapidly degraded (Wehtje et al. 1987). Cultural practices, including the method of herbicide application and subsequent tillage, can alter the persistence and distribution of a herbicide in the soil (Wixson and Shaw 1992).

These imidazolinones may persist and injure rotational crops, such as corn, under certain conditions (Coffman et al. 1993; Loux et al. 1989). Injury symptoms include stunted plants, shortened internodes, and yield reduction. However, imidazolinone-resistant corn varieties, which have a modified acetolactate synthase (ALS), have been marketed since 1995 (Shaner et al. 1996). Anderson and Georgeson (1989) found eight mutant corn ALS genes (XA17, AC17, UV18, QT15, QJ22, XS40, XI12, and ZA54) with altered affinity for imidazolinone or sulfonylurea herbicides, but only XI12 has been used in the imidazolinone-tolerant corn varieties marketed in Brazil (Almeida et al. 2002).

The development of imidazolinone-tolerant corn provided the opportunity to develop new compounds for weed control in corn, and a mixture of imazapic and imazapyr (525 + 175 g ai/kg of formulated product, respectively) was registered in Brazil (Rodrigues and Almeida 1998). This mixture provides excellent control of the main weeds in corn, such as alexandergrass [*Brachiaria plantaginea* (Link) A.S. Hitchc.], southern sandbur (*Cenchrus echinatus* L.), purple nutsedge (*Cyperus rotundus* L.), wild poinsettia (*Euphorbia heterophylla* L.), hairy beggarticks (*Bidens pilosa* L.), and tropical spiderwort (*Commelina benghalensis* L.) (Almeida et al. 2002). Although the recommended field rates are relatively low (52.5 + 17.5 g/ha of imazapic and imazapyr, respectively) there is a risk of carryover to certain rotational crops planted after imidazolinone-tolerant corn (Rodrigues and Almeida 1998).

The objective of this research was to determine the persistence and carryover effect of a mixture of imazapic and imazapyr on edible bean, soybean, corn, and wheat planted after imidazolinone-tolerant corn in two locations in Brazil under no-tillage and conventional tillage systems.

MATERIALS AND METHODS

Four field experiments were established at two different locations in the State of Paraná (PR), Brazil. Two were in the north of the state—Agricultural Research Station of the University of Londrina, Londrina, PR, in a clay soil (78% clay, 14% silt, and 8% sand, 3.5% organic matter, and pH of 4.7). The other two were at the Agricultural School of Palmeira, Palmeira, PR, in the south of the state, in a sandy-loam soil (28% clay, 14% silt, and 58% sand, 4.7% organic matter, and pH of 5.8). The monthly precipitation (mm) and air temperature (C) during the time of the experiments are presented in Table 1. For each location, the experiment was repeated side by side in a tillage planting system and in a no-tillage planting system. In the tillage system, the soil was prepared by disking followed by two harrowings before planting. The no-till plots were in an area that had not been tilled for 3 yr. The no-till plots were treated with glyphosate at 1,080 g ae/ha just before planting to control emerged weeds. The no-tillage plots were approximately 70% covered with straw from a previous wheat crop at the time of planting. A split-plot treatment arrangement in a randomized block design with three replications was used. Main plots were herbicide treatments, a mixture of imazapic and imazapyr at 0, 52.5 + 17.5, and 105 + 35 g ai/ha, respectively, and subplots were five different intervals between the herbicide application and the rotational crops' planting date: 0, 30, 60, 90, and 120 d after treatment (DAT). Imidazolinone-tolerant corn (DKB CL 909[3]) was planted 5 cm deep at a population of 85,000 seeds/ha in 70-cm row spacings in all the plots. Edible beans, corn, soybean, and wheat were planted as rotational crops. Subplots were 7.2 by 9 m

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with four rows of each crop and the data collected from the two central rows of each subplot.

The mixture of imazapic and imazapyr was applied POST with a nonionic surfactant at 0.15% (v/v) when the imidazolinone-tolerant corn was at the 2- to 3-leaf stage on October 27, 1999, in Londrina and October 30, 1999, in Palmeira. A CO_2 pressurized backpack sprayer with 80,015 low-pressure nozzles delivering 170 L/ha at 190 kPa was used for all herbicide applications. One fifth of each plot was destroyed at each planting interval by cutting the corn plants at the soil line and placing the stalks in the row. The rotational crops were planted between the corn rows in each plot. Edible bean (IAPAR 14[4]) seed was planted 4 cm deep at a population of 330,000 seed/ha in 45-cm row spacings. Soybean (Embrapa 48[5]) seed was planted 5 cm deep at a population of 380,000 seed/ha in 45 cm row spacings. Corn (DKB 909[6]) was planted 5 cm deep at a population of 85,000 seed/ha in 70-cm row spacings, and wheat (IAPAR 78[7]) was planted 3 cm deep at a population of 970,000 seed/ha in 20-cm row spacings. The planting date of the rotational crops in Londrina were October 27, November 26, December 27 in 1999 and January 25 and February 24 in 2000; and in Palmeira were October 31, November 29, December 28 in 1999 and January 28 and February 27 in 2000. All weeds were removed by hand weeding during the growing season.

Visual crop injury was assessed 14 and 28 d after planting (DAP) for each rotational crop planting date based on a 0 to 100 scale (0 = no injury; 100 = crop death). The grain of all rotational crops was hand harvested and yields were adjusted to 13% moisture.

Ten 12-cm-diameter soil samples per plot were collected to a depth of 10 cm in all plots at 0, 30, 60, 90, and 120 DAT and stored in a freezer until they were analyzed by the cucumber bioassay as described by Cobucci et al. (1998) and by high-performance liquid chromatography analysis using the procedure of Rodrigues et al. (2000). In the cucumber bioassay, soil from each treatment was placed in four 1.5-kg plastic pots and five seeds of cucumber (Caipira[8]) were planted in each pot. The pots were placed in the greenhouse kept at 25/18 C with a 12-h photoperiod under natural sunlight (120 μM/m^2/s). The soil was not fertilized and the pots were watered daily. Shoot height and shoot dry weight were measured at 28 DAP.

[4] IAPAR, P.O. Box 481, Londrina, PR, Brazil.
[5] EMBRAPA, Soybean, P.O. Box 231, Londrina, PR, Brazil.
[6] COROL, P.O. Box 96, Rolândia, PR, Brazil.
[7] IAPAR P.O. Box 481, Londrina, PR, Brazil.
[8] COROL, P.O. Box 96, Rolândia, PR, Brazil.

Herbicide concentrations in the soil over time were subjected to regression analysis for each location, tillage system, and rate to obtain herbicide degradation equations. Regression analyses were subjected to polynomial models the coefficients of which were tested using the *t* test ($P \leq 0.05$). The selected models showed significance for all coefficients or had the highest r^2. The PINYD of each follow crop, tillage system, and location, and the cucumber planting interval with no injury were calculated from the equations that described the relationship between yield and time after imidazolinone treatment for each crop and the relationship between cucumber dry weight 28 DAP and time after imidazolinone treatment, respectively. DT_{50} for each location, system, and rate was calculated from the regression equations that described the loss of herbicides from the plots and using the initial concentrations (*Y* intercept) predicted in the equation. The lowest concentration of the herbicide in the soil that caused no yield loss (LCHS) was calculated based on the PINYD and the degradation curves for each of the herbicides according to the model of Cobucci et al. (1998).

RESULTS AND DISCUSSION

The DT_{50} of imazapic and imazapyr were similar, but the DT_{50} for both herbicides was greater in Londrina than in Palmeira (Table 2). The difference between the two sites was probably due to the lower pH and greater clay content of the soil in Londrina compared with Palmeira. Except for imazapyr in Palmeira, the DT_{50} tended to increase slightly in no-till compared with conventional tillage, but the differences were not great (Table 2).

The rate of dissipation of imazapyr in these soils was similar to that reported by Michael and Neary (1993) for forest soil in the southern United States, where the DT_{50} for imazapyr was between 34 and 65 d. However the half-life of imazapic is reported as 120 d (Vencill 2002). The difference between the half-life of imazapic found in this study and the reported half-life in Vencill (2002) is likely due to the more favorable conditions for microbial degradation of imidazolinones in the tropical environment of southern Brazil.

Although there is evidence that the persistence of pesticides may be affected when they are combined (Fogg and Boxall 2003), we did not measure the rates of dissipation of the two imidazolinones separately. Because these herbicides are always applied together in imidazolinone-resistant corn, these results are the worst-case scenario in terms of persistence of the two herbicides.

PINYD was calculated for each rotational crop. Soy-

Table 2. Soil residue equations (derived from high-performance liquid chromatography) and dissipation time (DT_{50}) for imazapic and imazapyr in Londrina and Palmeira, PR, Brazil.

Herbicide	Location	Tillage system	Herbicide rate	Soil residue equation	r^2	DT_{50}[a]
			g ai/ha			
Imazapic	Londrina	Tilage	52.5	$Y = 95.4637 - 1.2888x + 0.00486x^2$	0.98	45
			105	$Y = 184.83 - 3.54442x + 0.03728x^2 - 0.00016x^3$	0.97	40
		No-till	52.5	$Y = 88.7487 - 0.72922x + 0.00078x^2$	0.99	66
			105	$Y = 162.3746 - 1.0259x - 0.00555x^2 + 0.00003x^3$	0.92	65
					Average[b]	54.0 ± 13.4
Imazapic	Palmeira	Tillage	52.5	$Y = 72.5712 - 1.4201x + 0.010x^2 - 0.000027x^3$	0.98	32
			105	$Y = 147.2644 - 4.9618x + 0.05685x^2 - 0.00021x^3$	0.95	19
		No-till	52.5	$Y = 76.5944 - 1.3057x + 0.00562x^2$	0.99	35
			105	$Y = 150.2961 - 4.6316x + 0.0495x^2 - 0.00018x^3$	0.97	21
					Average[b]	26.8 ± 7.9
Imazapyr	Londrina	Tillage	17.5	$Y = 31.1571 - 0.39095 + 0.001166x^2$	0.98	50
			35	$Y = 61.3466 - 1.83593x + 0.021997x^2 - 0.0000904x^3$	0.99	22
		No-till	17.5	$Y = 30.7920 - 0.3280x + 0.00071x^2$	0.97	53
			35	$Y = 60.1044 - 1.14857x + 0.00957x^2 - 0.00003x^3$	0.99	35
					Average[b]	40.0 ± 14.4
Imazapyr	Palmeira	Tillage	17.5	$Y = 27.0111 - 0.3416x + 0.00093x^2$	0.95	45
			35	$Y = 42.8104 - 1.0113x + 0.00561x^2$	0.95	25
		No-till	17.5	$Y = 26.3289 - 0.2813x - 0.00114x^2 + 0.0000135x^3$	0.99	43
			35	$Y = 45.6156 - 1.4867x + 0.01701x^2 - 0.00006x^3$	0.95	20
					Average[b]	33.3 ± 12.6
	Londrina			Average[c]		47.0 ± 14.9
	Palmeira			Average[c]		30.0 ± 10.4

[a] DT_{50}, dissipation time of 50% of the herbicide.
[b] Average across tillage systems and rates
[c] Average across herbicides, tillage systems, and rates.

bean was the least sensitive crop to imazapic and imazapyr residues in the soil and the means of the PINYD in Londrina and Palmeira were 87 and 88 d, respectively. Wheat and edible bean showed intermediate sensitivity compared with the other crops and the PINYD means were 99 and 98 d for Londrina and 91 and 97 d for Palmeira, respectively. Corn was the most sensitive rotational crop, and the PINYD means were 117 and 97 d in Londrina and Palmeira, respectively.

Ulbrich et al. (1998) worked with soils in the Londrina region and reported corn PINYDs after soybean of 87 d for imazapyr and 112 d for imazaquin. Wixson and Shaw (1992) reported greater tolerance of corn to imazapic (35 g ai/ha) than to imazaquin (6 g ai/ha) when the herbicides were incorporated into the soil and the crop planted immediately. Bovey and Senseman (1998) found that corn was less tolerant to imazapyr residues compared with soybean or edible beans. Coffman et al. (1993) also worked with imazapyr but at much higher levels (2.2 kg ai/ha) and, based on the visual damage, determined an interference period of 82 d for soybeans and 436 d for wheat and corn. Gonçalves et al. (2001), in field studies with imazapyr at 375 g/ha in sugar cane (*Saccharum officinarum* L.), reported PINYDs for beans of 98 d. Rodrigues (1993) worked with bioassays and determined a period of 93 d to minimize the carryover of imazaquin to corn. Imazapyr can synergize the activity of imazethapyr and imazaquin when applied POST to johnsongrass (*Sorghum halepense* (L.) Pers.) and pitted morningglory (*Ipomoea lacunosa* L.) (Riley and Shaw 1988). While there have been no reports of synergism between imazapyr and imazapic, it is possible that this phenomenon occurs. The PINYDs measured in this study are undoubtedly related to the presence of both imidazolinones in the soil and should be the worst case for carryover to sensitive rotational crops.

LCHS was calculated based on the PINYD and the degradation curve for each of the herbicides according to the model of Cobucci et al. (1998). The LCHS showed a direct relationship with the sensitivity of the crops to the imidazolinone mixture (Table 3). In general, soybean had the lowest PINYD and also tolerated the highest concentration of the herbicides in the soil. The mean of the soil level for both herbicides was 43 ppb in Londrina and 10 ppb in Palmeira. Cobucci et al. (1998) reported that the LCHS for imazamox following beans was 10, 40, and <5 ppb for corn, rice, and sorghum, respectively, in soils in the Brazilian savannah.

There was a distinct difference in the LCHS between Londrina and Palmeira. The LCHS in the clay soil at Londrina was two to five times higher compared with the sandy loam soil at Palmeira (Table 3). Both imida-

Table 3. Edible bean, corn, soybean, and wheat planting interval with no yield drag (PINYD) after imazapic + imazapyr application and lowest concentration of herbicide in the soil (LCHS) that does not affect yield of rotational crops in Londrina and Palmeira, PR, Brazil.

Rotational crop	Location	Tillage system	Herbicide rate	Follow crop yield equation	r^2	PINYD	LCHS
			g ai/ha			d	ppb
Edible bean	Londrina	Tillage	52.5 ± 17.5	$Y = 1413.14 - 3.3280x + 0.1382x^2 - 0.00087x^2$	0.82	87	26.5
			105 ± 35	$Y = 1105.00 + 4.09444x$	0.77	107	36.7
		No-till	52.5 ± 17.5	$Y = 1547.61 + 6.6402x - 0.1185x^2 + 0.00056x^2$	0.94	95	32.9
			105 ± 35	$Y = 1130.71 + 9.7357x - 0.0533x^2$	0.97	104	38.4
					Average[a]	98.1 ± 9.4	33.6 ± 5.32
Edible bean	Palmeira	Tillage	52.5 + 17.5	$Y = 1527.67 + 1.3500x$	0.74	103	5
			105 + 35	$Y = 1095.71 + 2.9562x + 0.1132x^2 - 0.0008x^3$	0.93	90	8.2
		No-till	52.5 + 17.5	$Y = 1551.0 + 1.55220x$	0.91	102	2.4
			105 + 35	$Y = 1101.76 - 9.1508x + 0.358x^2 - 0.0020x^2$	0.95	91	7.1
					Average[a]	96.3 ± 6.7	5.6 ± 2.5
Corn	Londrina	Tillage	52.5 + 17.5	$Y = 6880.33 - 1.3425x - 0.1944x^2 + 0.00067x^3$	0.97	110	15
			105 + 35	$Y = 5276.42 + 17.7603x - 0.1732x^2$	0.78	123	6.3
		No-till	52.5 + 17.5	$Y = 7486.66 - 20.8777x$	0.99	118	15.9
			105 + 35	$Y = 5522.00 + 15.5666x - 0.1675x^2$	0.84	116	22.5
					Average[a]	116.6 ± 5.7	14.9 ± 6.63
Corn	Palmeira	Tillage	52.5 ± 17.5	$Y = 7943.95 + 19.8161x - 0.1096x^2 - 0.00167x^3$	0.99	97	7.3
			105 + 35	$Y = 6283.85 + 59.6261x - 0.5908x^2$	0.85	110	6.1
		No-till	52.5 + 17.5	$Y = 7650.74 + 12.1554x + 0.2001x^2 - 0.0035x^3$	0.99	88	7.5
			105 + 35	$Y = 7193.78 - 46.2718x + 1.3968x^2 - 0.0092x^3$	0.86	95	6.9
					Average[a]	97.2 + 9.2	6.9 ± 0.6
Soybean	Londrina	Tillage	105 + 35	$Y = 1818.52 + 8.6891x - 0.0058x^2 - 0.0004x^3$	0.84	92	54.1
			105 + 35	$Y = 2057.57 + 24.3637x - 0.4063x^2 + 0.00179x^3$	0.93	104	38.6
		No-till	52.5 + 17.5	$Y = 2595.00 + 0.53333x - 0.04074x^2$	0.84	80	44.8
			105 + 35	$Y = 2057.57 + 24.3637x - 0.4063x^2 + 0.00179x^3$	0.93	104	38.6
					Average[a]	87.2 ± 13.8	43.5 ± 7.9
Soybean	Palmeira	Tillage	52.5 + 17.5	$Y = 2494.81 + 7.4738x - 0.0887x^2$	0.96	73	18.7
			105 + 35	$Y = 2061.52 + 12.7206x - 0.1021x^2$	0.94	90	8.2
		No-till	52.5 + 17.5	$Y = 2229.62 + 13.5865x - 0.1132x^2$	0.96	87	8
			105 + 35	$Y = 1756.47 + 17.7349x - 0.1145x^2$	0.99	103	6.1
					Average[a]	88.3 ± 12.5	10.3 ± 5.7
Wheat	Londrina	Tillage	52.5 ± 17.5	$Y = 1404.97 + 14.8062x + 0.0410x^2 - 0.0004x^3$	0.99	76	33.9
			105 ± 35	$Y = 628.33 + 28.7222x - 0.0777x^2$	0.95	116	21.3
		No-till	52.5 ± 17.5	$Y = 1405.0 + 13.5166x$	0.89	94	33.2
			105 ± 35	$Y = 903.66 + 21.4166x - 0.0379x^2$	0.95	111	29.7
					Average[a]	99.2 ± 18.2	29.5 ± 5.8
Wheat	Palmeira	Tillage	52.5 + 17.5	$Y = 1172.00 + 16.6778x$	0.97	83	13.2
			105 + 35	$Y = 764.85 + 10.8187x + 0.2247x^2 - 0.0013x^3$	0.92	102	8.5
		No-till	52.5 + 17.5	$Y = 998.07 + 27.8406x - 0.1559x^2 + 0.0006x^3$	0.99	84	9.3
			105 + 35	$Y = 532.14 + 12.0145x + 0.3132x^2 - 0.0021x^3$	0.99	94	6.9
					Average[a]	90.8 ± 8.8	9.5 ± 2.7

[a] Averaged across rates.

zolinones degraded more rapidly at Palmeira than at Londrina, but the PINYDs for the rotational crops were similar at both sites. The difference in the LCHS between the two sites suggests that the herbicides were more bioavailable both for degradation and for the follow crops.

These results show that there is a poor relationship between the soil residue levels of imazapic and imazapyr and rotational crop injury because of the differences in the bioavailability of herbicide residues in different soil types (Bresnahan et al. 2002). Bioassays may be a much better indicator of potential injury to rotational crops than soil residue levels. Cucumbers are highly sensitive to soil residue levels of imidazolinones and have been used to bioassay soils (Ulbrich et al. 1998). The cucumber bioassay was conducted at each planting interval at each site and the interval with no injury to cucumber (CPINI) was calculated. The CPINI across all treatments averaged 128 d at Londrina and 107 d at Palmeira (Table 4), which were longer than the PINYD for the crops at these sites. The sensitivity of cucumber to soil residue levels of imazapic and imazapyr could be very useful as a tool to indicate when it is safe to plant rotational crops. If cucumber is not injured when grown in soil that had been treated with imazapic plus imazapyr, then the rotational crops could be safely planted.

The results of these experiments showed a much faster soil dissipation time of imazapic and imazapyr under subtropical conditions compared with previously reported soil dissipation times under temperate conditions. In

Table 4. Cucumber planting interval with no weight reduction (CPINI) after imazapic + imazapyr application at Londrina and Palmeira, PR, Brazil.

Location	System	Herbicide rate	Cucumber injury equation	R^2	CPINI
		g ai/ha			d
Londrina	Tillage	52.5 + 17.5	$Y = 4.87 + 0.1150x - 000042x^2$	0.96	118
		105 + 35	$Y = 3.48493 + 0.05303x + 0.00110x^2 - 0.00000773x^3$	0.99	143
	No-till	52.5 + 17.5	$Y = 5.2635 + 0.07097x$	0.96	116
		105 + 35	$Y = 3.16800 + 0.08350x$	0.98	136
				Average[a]	128 + 13.3
Palmeira	Tillage	52.5 + 17.5	$Y = 3.2625 + 0.07885x$	0.99	101
		105 + 35	$Y = 2.42175 - 0.02348x + 0.00237x^2 - 0.00001294x^3$	0.99	108
	No-till	52.5 + 17.5	$Y = 4.99564 - 0.03652x + 0.00288x^2 - 0.00001653x^3$	0.99	106
		105 + 35	$Y = 2.79579 - 0.02329x + 0.00291x^2 - 0.0001653x^3$	0.99	113
				Average[a]	107 + 5.0

[a] Average across systems and rates.

Brazil, edible bean, corn, and soybean are normally cultivated during the summer season, in rotation with corn, and, although wheat is cultivated in the winter, the period between herbicide application and planting date of wheat is usually greater than 150 d. Thus, the risk of carryover damage due to the application of imazapic plus imazapyr (52.5 + 17.5 g ai/ha) is very low.

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